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EUROPA ORBITER MISSION TRAJECTORY DESIGN

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The Europa Orbiter mission will place a spacecraft into a low-altitude orbit about Europa to determine whether a subsurface ocean exists on Europa. The approach and orbit insertion phase at Jupiter utilizes a Ganymede gravity-assist flyby and an orbit insertion maneuver performed at about 12.5 R_J perijove range. This is followed by a nearly ballistic orbital tour lasting about a year during which the orbital period is reduced to 10 days (3 times Europa's period) or less. Finally, in the "endgame" phase, a series of nearly resonant Europa encounters and apojove maneuvers further reduce the period about Jupiter to be nearly commensurate with that of Europa, leading to insertion about Europa and a 30 day orbital mission. Third body perturbations are used to reduce orbital insertion ΔV at Europa significantly.

INTRODUCTION

The Europa Orbiter mission is the first of three new missions in NASA's Outer Planets/Solar Probe Program. It will place a spacecraft into a low-altitude orbit about Europa to investigate whether or not a subsurface ocean exists at the present time. (Analysis of science data gathered during the Galileo mission suggests that an ocean existed in the past.) Europa Orbiter will characterize the distribution of any subsurface liquid water and overlying ice layers and help to identify possible future lander sites. A formal start is expected with the FY2000 NASA budget, and launch is planned for November 2003. This paper will describe the design for the direct Earth-Jupiter trajectory for the 2003 launch opportunity.

The other two missions in the program, Pluto-Kuiper Express (PKE) and Solar Probe, are planned to be launched in December 2004 and February 2007, respectively. The three missions share common development of avionics, the power system, transponder, and flight and ground software.

The mission design for Europa Orbiter is driven by the need to minimize ΔV and radiation dosage. The trajectory design includes several phases common to Galileo trajectory design (especially the 1986 direct trajectory launch opportunity), including a broken-plane maneuver (BPM), a gravity assist satellite flyby before perijove to reduce orbit insertion ΔV, a Jupiter orbit insertion maneuver (JOI), a similar 200-day initial orbit, a perijove raise maneuver (PJR), and gravity-assist flybys as part of a satellite tour used to shape the trajectory, including reducing or increasing orbital period and perijove range.

In the latter stages of the satellite tour, also referred to as the "endgame" phase, multiple, nearly resonant flybys of Europa are combined with perijove raising maneuvers at apoapsis to maintain perijove near Europa's orbit and nearly match Europa's orbital period. Then, third-body perturbations from Jupiter cause the spacecraft to be loosely "captured" by Europa. Finally, a Europa orbit insertion maneuver (EOI) places the spacecraft into a nearly circular low-altitude orbit about Europa. A 30-day orbital mission is

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planned, including a gravity field mapping and altimetry phase and an ice-penetrating radar mapping and imaging phase.

LAUNCH AND ARRIVAL PHASES

Interplanetary Trajectory and Jupiter Arrival

Europa Orbiter is currently planned to be launched on an Atlas V-class vehicle utilizing a Star 48V upper stage. For a constant C_3 of 80 km^2/s^2, a 14 day launch period covers November 11 to 24, 2003, and permits an injected mass in the range of 1550 kg. Figure 1 shows the interplanetary trajectory for the opening of the launch period. The direct trajectory requires a broken-plane maneuver (BPM) which varies in magnitude from about 280 m/s for arrival in August 2006 to nearly zero for arrival about one year later.

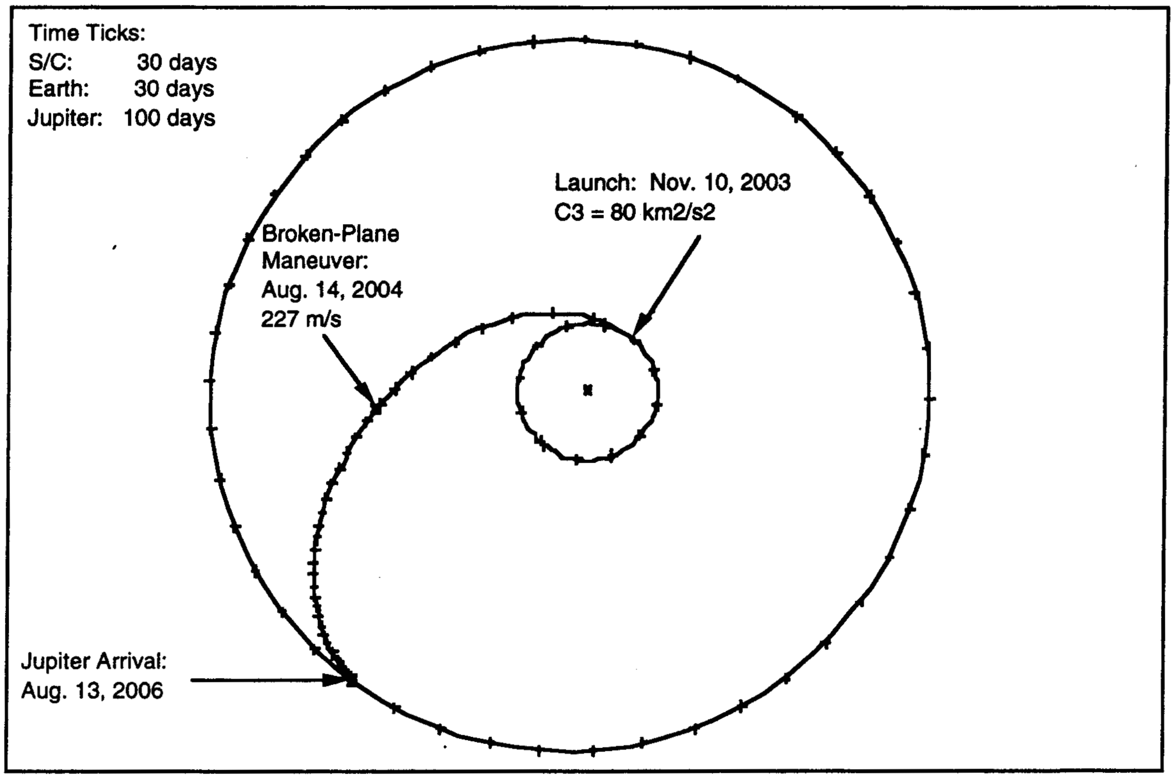


Figure 1 Interplanetary Trajectory (Opening of Launch Period)

Over the same period, the Jupiter arrival V_∞ is rising, thereby increasing the JOI ΔV for later arrival dates. A strategy of allowing the arrival date to vary over the launch period permits the combination of ΔV for the broken-plane maneuver and Jupiter orbit insertion to remain fairly constant. The total ΔV currently allocated for the mission is about 2.3 km/s, which includes about 1.0 km/s for the combination of BPM, JOI, and PJR, another 1.0 km/s for the endgame and Europa orbit insertion, and 0.3 km/s for navigation and statistical maneuvers.

Perijove Range for Performing JOI

A flyby of either Io or Ganymede prior to perijove can provide a substantial gravity assist to reduce the size of the orbit insertion maneuver. The biggest difference between using Io or Ganymede is that perijove (and JOI) must occur below that satellite's range from Jupiter (<5.9 Jupiter radii, or R_J, for Io and <15 R_J for Ganymede). The magnitude of JOI is, of course, much less when performed at a lower perijove range. In fact, early studies[1] proposed that JOI be performed at a range of 1.02 R_J. Very low perijoves introduce problems associated with ring plane crossing, a heavy radiation dosage, finite burngravity losses, the need for extremely precise targeting, and general operational complexity. Moreover, the savings from performing JOI at a very low perijove are offset by the need for larger perijove raise maneuvers. A satellite tour to reduce period and control perijove usually begins with a Ganymede flyby after PJR, since it is the most effective at reducing energy.

Figure 2 compares the ΔV for BPM, JOI, PJR and their total for the three cases of (1) no gravity assist, (2) inbound Io flyby at 500 km, and (3) inbound Ganymede flyby at 500 km. In all cases the initial orbit period was 200 days, and the post-G1 perijove was 10.9 R_J. The minima in the total ΔV curves occurring at about 5.15 R_J for Io and at about 12.4 R_J for Ganymede are a direct result of using a fixed post-G1 perijove of 10.9 R_J. This approach is valid and necessary, however, if one wishes to compare the ΔV costs to be able to begin a satellite tour at Ganymede with approximately the same conditions.

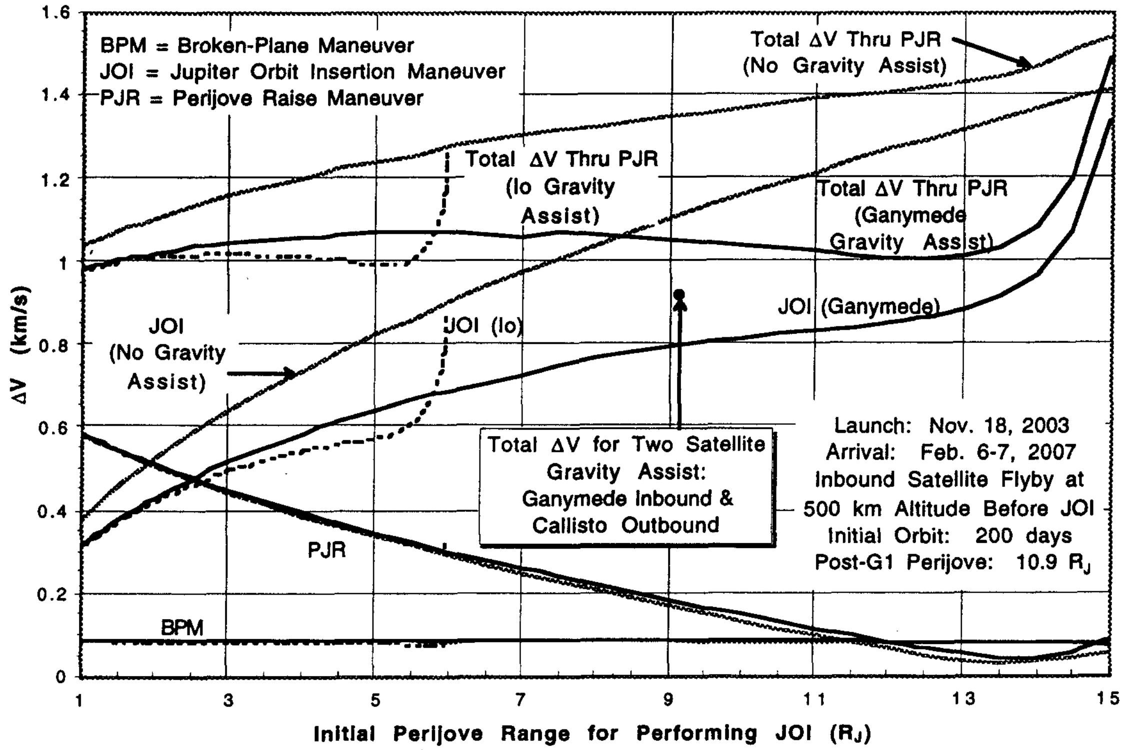


Figure 2 Deterministic ΔV Through PJR as a Function of Initial Perijove Range at JOI for Cases of (1) No Gravity Assist, (2) Io Gravity Assist, and (3) Ganymede Gravity Assist

Further studies[2] comparing an Io flyby prior to JOI performed at 5 R_J perijove with a Ganymede flyby prior to JOI performed at 12.5 R_J demonstrated that a Ganymede flyby at 350 km altitude was equivalent in ΔV cost to an Io flyby at 500 km altitude. While consideration of issues such as volcanic ejecta would probably require an Io flyby at ≥ 500 km altitude, a Ganymede flyby at 350 km would probably represent no special hazard to the spacecraft. Thus the strategy of utilizing an inbound Ganymede flyby at 350 km altitude, followed by the Jupiter orbit insertion maneuver performed at 12.5 R_J was adopted. The initial orbit period was selected to be 200 days, although several cases have been studied with different initial orbit period, as well as different initial perijove range.

Two-Satellite Gravity Assist

An alternate strategy, which is not part of the baseline and needs further study, is to perform two gravity-assist flybys on Jupiter approach, one inbound before JOI and the second outbound between JOI and apojove. Figure 2 shows the benefit of using a Ganymede gravity-assist flyby at 500 km on the inbound leg and a Callisto gravity-assist flyby at 1000 km on the outbound leg. The perijove range for JOI must be free for this situation and is about 9.13 R_J; the total ΔV for BPM + JOI + PJR is 0.92 km/s (about 80 m/s better than the Ganymede trajectory for a 12.5 R_J initial perijove). It should be possible to find a two-satellite gravity assist trajectory for arrivals at 50 day intervals, since the synodic period between Ganymede and Callisto is 50 days. The perijove range for JOI may differ substantially for other arrival dates. Additional navigation studies will also need to be done to evaluate whether dispersions from performing JOI would be small enough to make a post JOI flyby feasible without a clean-up maneuver in the 42 hours between JOI and the Callisto encounter.

Launch Period

Figure 3 shows how the deterministic ΔV through PJR varies across the launch period when using an optimal minimum-ΔV arrival date strategy. The total deterministic ΔV for a 14 day launch period ranges from about 0.96 km/s to 1.02 km/s.

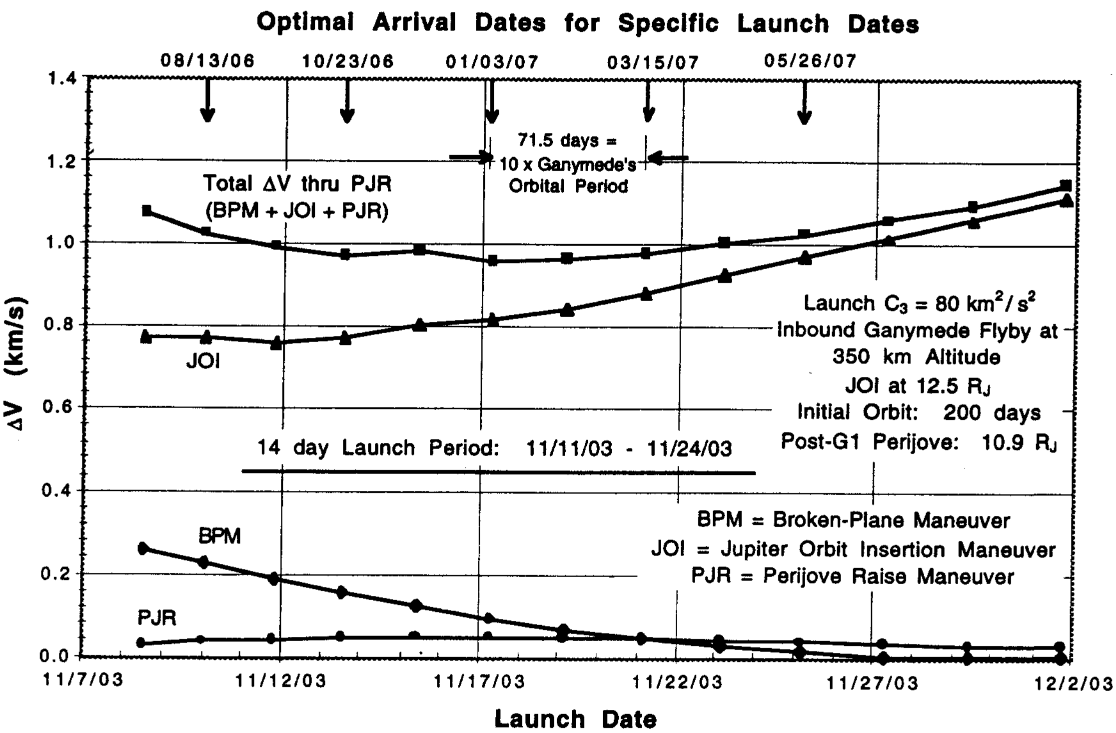


Figure 3 Deterministic ΔV Through PJR as Function of Launch Date

The launch and arrival dates actually considered correspond to a 16 day launch period (11/10/03 through 11/25/03) and about a 9.4 month arrival period encompassing 41 different possible arrival dates (8/13/06 through 5/26/07), one every 7.15 days (Ganymede's orbit period). Each of these arrival dates permit a gravity assist flyby of Ganymede prior to JOI.

SATELLITE TOUR

Constraints on Tour Design

The satellite tours designed for Europa Orbiter do not have science-oriented restrictions such as a variety of satellites, inbound/outbound or lightside/darkside flybys. The prime purpose of the encounters is to reduce the orbital period and to control the perijove range using a minimum amount of ΔV.

Rotation/counter-rotation of the orbit may become an issue as a possible way to control the node of the orbit about Europa by controlling the line of apsides of the orbit about Jupiter upon entry into the endgame phase. The requirement on the node is discussed in a later section. This aspect and the issue of telecom visibility during EOI must be studied further.

One complication of the variable arrival date strategy is that the length of the tour is also variable. The orbital phase of the mission is desired to take place when the spacecraft range to Earth is within 5 AU, (where 1 AU = mean Earth-Sun distance). This time period is basically about 5.5 months long and centered around opposition (July 10, 2008). This requirement may be slightly relaxed for late arrival dates, for which it is difficult to design extremely short-duration satellite tours. For the late arrival dates, there is a strong desire that the mission be completed prior to the January 2009 solar conjunction, however. Maneuvers and encounters must be avoided for a period around solar conjunction (defined for this mission to be specifically, from 4 days before to 4 days after the period when the Sun-Earth-Spacecraft angle is < 3 degrees, approximately a 2-week period).

Figure 4 shows the various phases of the mission and how dates of solar conjunction and opposition drive the duration of the satellite tour. A 200-day initial orbit after JOI is assumed for computing the tour start date, except for the late launch date, where an earlier tour start helps avoid solar conjunction in late 2007 and increases the allowable tour length. The minimum/maximum durations shown following tour start include both the ballistic satellite tour and the endgame. The permissible times for EOI range from 30 days before the start to 30 days before the end of the time when the Earth range is < 5 AU.

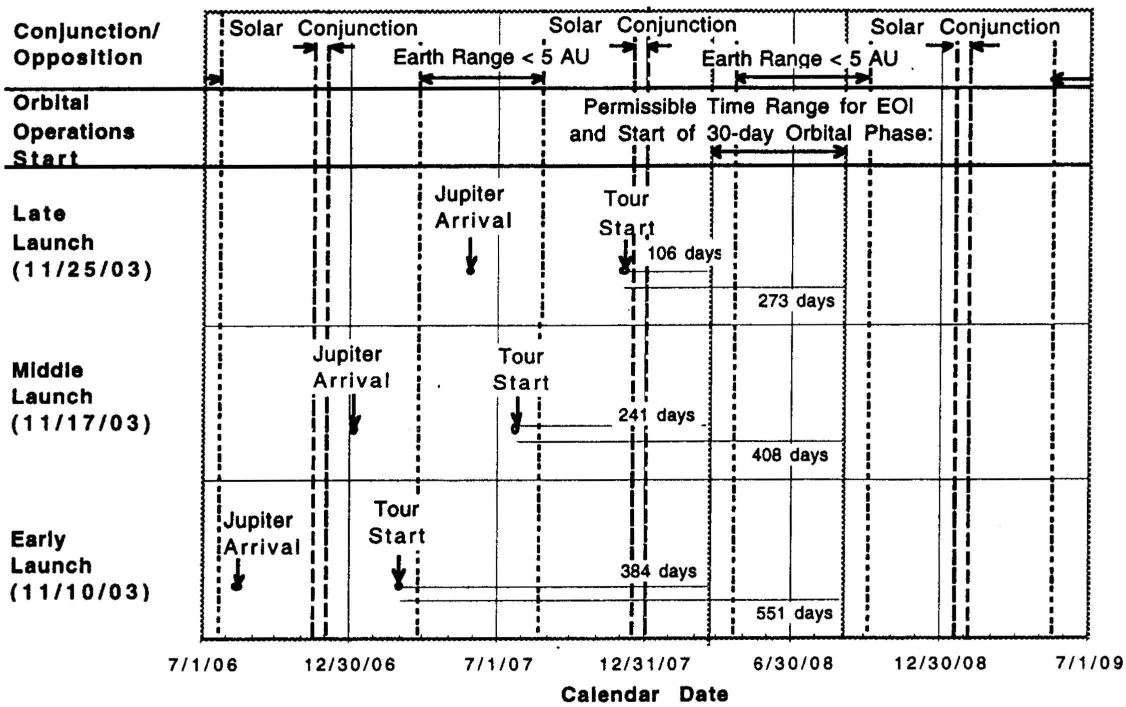


Figure 4 Relationship of Mission Events to Solar Conjunction and Earth Range

The spacecraft will have radiation shielding of 100 mils aluminum and will be able withstand a total of 4 Mrad of radiation. Half of this dosage will occur in the 30-day orbital operations phase. In order to minimize radiation dosage during the satellite tour, the perijove is constrained to be no lower than about

8.8 R_J in the tour design phase. The number of phasing orbits (on which no targeted satellite encounter occurs) that have low perijoves also needs to be minimized.

Lastly, in order to avoid multiple encounters on a single orbit which could present problems for development of a navigation strategy, tours are being designed with the restriction that there be no nontargeted (i.e., secondary) encounters with flyby altitudes less than 50,000 km.

Design of the Satellite Tour

With the exception of a few tours, all the preliminary satellite tour design has been conducted at Purdue University by Professor James Longuski and graduate students Eugene Bonfiglio, Nathan Strange and Andrew Heaton[3,4]. Using an automated tour design tool, based on two-body conics, the Purdue team analyzed a very large number of trajectories and delivered the ones that best satisfied the mission constraints and had a low V_∞ at the first Europa encounter near the end of the tour phase. The authors then optimized those trajectories using the CATO[5] program (Computer Algorithm for Trajectory Optimization) using numerically integrated trajectories and actual planetary and satellite ephemerides. Tours were generated for the beginning, middle, and end of the launch period. In general, the resulting trajectories are ballistic (or nearly so) and are the optimized, integrated equivalent of the conic trajectories designed by the Purdue team. Sometimes the integrated trajectories found with CATO differ from the conic trajectories if there are one or more non-targeted satellites at an altitude < 100,000 km.

The tour begins at an inbound Ganymede flyby following PJR and targets to a second inbound Ganymede flyby (designated G1 and G2, respectively). As with the start of the Galileo satellite tour, these two Ganymede flybys greatly reduce the period, as well as remove the inclination from the orbit. The sequence continues with Ganymede flybys to reduce period and perijove, and with an occasional Callisto flyby to raise perijove whenever it drops below 8.8 R_J. One or more Europa flybys is usually possible within the sequence. The satellite tour phase ends with a Europa flyby which gives an orbital period less than three times the period of Europa (10.65 days) and a perijove around 9 R_J. All the encounters during this phase of the mission are designed such that the resulting trajectory is ballistic.

ENDGAME AND EOI

Resonant Encounters and Perijove Raise Maneuvers

The endgame phase of the Europa Orbiter mission a consists of a series of nearly resonant encounters with Europa combined with perijove raising maneuvers at apojove. The sequence of resonances is designed to permit the spacecraft's orbit to become nearly commensurate with that of Europa. Here the term "3:1" resonance will be used to mean that Europa completes 3 orbits about Jupiter while the spacecraft completes 1 orbit. A few years ago Chen-Wan Yen[6] of JPL found a sequence of encounters with Europa which reduced the period from 200 days to a 6:5 resonance and required 1.1 km/s in deterministic maneuvers. The end of that sequence (3:1, 5:2, 2:1, 5:3, 4:3, and 6:5) was used in the design of the first Europa endgame, described in Ref. 1.

This sequence is a balance between rapid decrease in period with few perijove passages and ΔV cost. Following an energy-reducing flyby of a satellite, both the perijove and apojove (and consequently the period) are lowered. Through repeated resonant flybys of Europa, it is possible to reduce the orbital period further and further, but the V_∞ magnitude will remain about the same without perijove raise maneuvers at apojove. The apojove maneuvers raise perijove (important to minimize the radiation dosage) and permit the spacecraft to encounter Europa with a lower V_∞.

If orbit insertion from a hyperbolic approach is attempted, the ΔV cost is lower for smaller values of V_∞. Figure 5 shows the relationship between the spacecraft orbital period, the theoretical lower limit on V_∞ at Europa and the EOI ΔV from a hyperbolic approach into a nearly circular orbit of altitude 200 km about Europa. The figure also shows the particular resonance associated with the V_∞ at Europa and spacecraft orbital period.

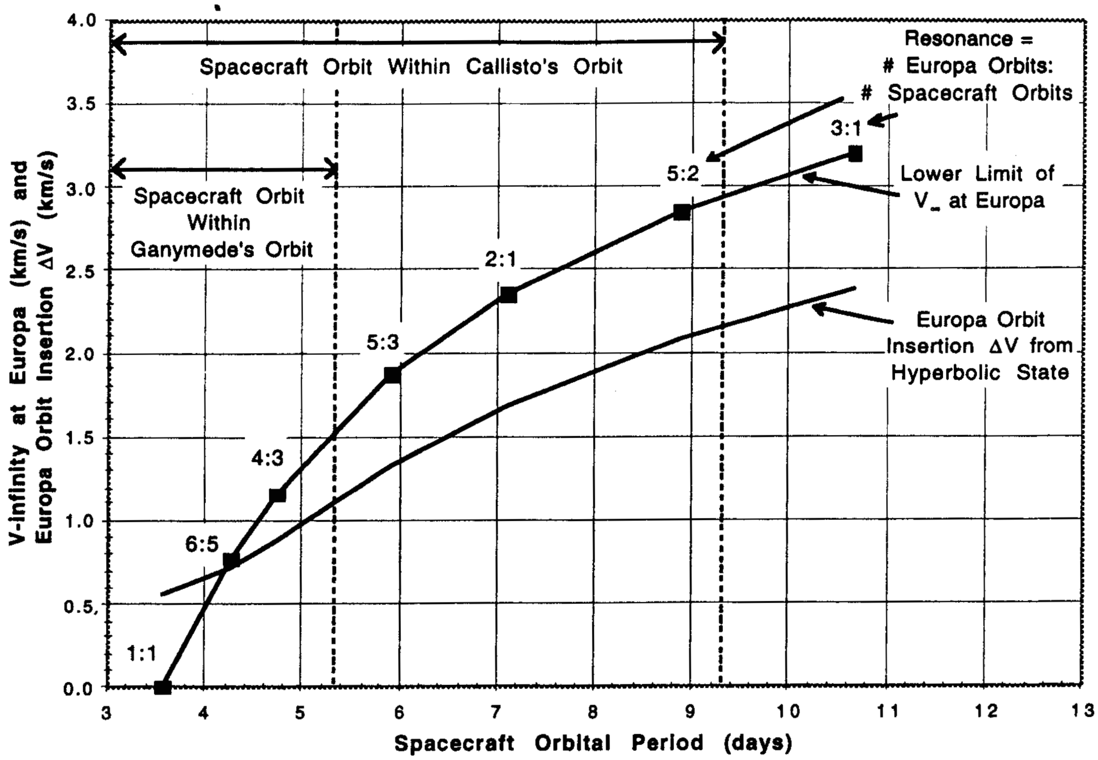


Figure 5 V_∞ at Europa and EOI ΔV from Hyperbolic Approach vs. Spacecraft Orbital Period

Effect of Third-Body Perturbations from Jupiter

Lowering the V_∞ for repeated encounters of Europa also permits the spacecraft to spend more time near Europa, and the combined gravitational effects of Jupiter and Europa on the spacecraft enable a "capture" of the spacecraft by Europa using third-body perturbations from Jupiter. For about the final 24 hours preceding Europa closest approach at the final encounter, the osculating state of the spacecraft is an ellipse with respect to Europa. Without an EOI maneuver, however, the spacecraft is not truly captured by Europa, and spacecraft escapes to a Jupiter orbit. If the orbit insertion maneuver is performed while the spacecraft is at closest approach to Europa and in this loosely-captured state, the EOI ΔV is 150 to 200 m/s less than for insertion from a hyperbolic approach at a 6:5 resonance.

Example Endgames

Figure 5 also shows that the spacecraft spends considerable time within Ganymede's orbit as its period is reduced to match that of Europa's. Tours can be designed to use Ganymede encounters to further reduce the spacecraft's period to the range of about 4.3 days. The endgame phase can be made much shorter with only one or two Europa flybys before capture (6:5 alone, or 4:3 and then 6:5 resonances, respectively). This endgame strategy method has Ganymede encounters near apojove and Europa encounters near perijove.

Figure 6 shows the trajectory for a traditional endgame. It has several (usually six) Europa flybys, alternating between inbound and outbound locations. The 9902 tour illustrated has several Ganymede non-targeted flybys (G14A, G15A, and G16A. The complexities of navigating a tour with nontargeted flybys is discussed later. Table 1 shows the details on the encounters and the ΔV which is representative of this type of endgame.

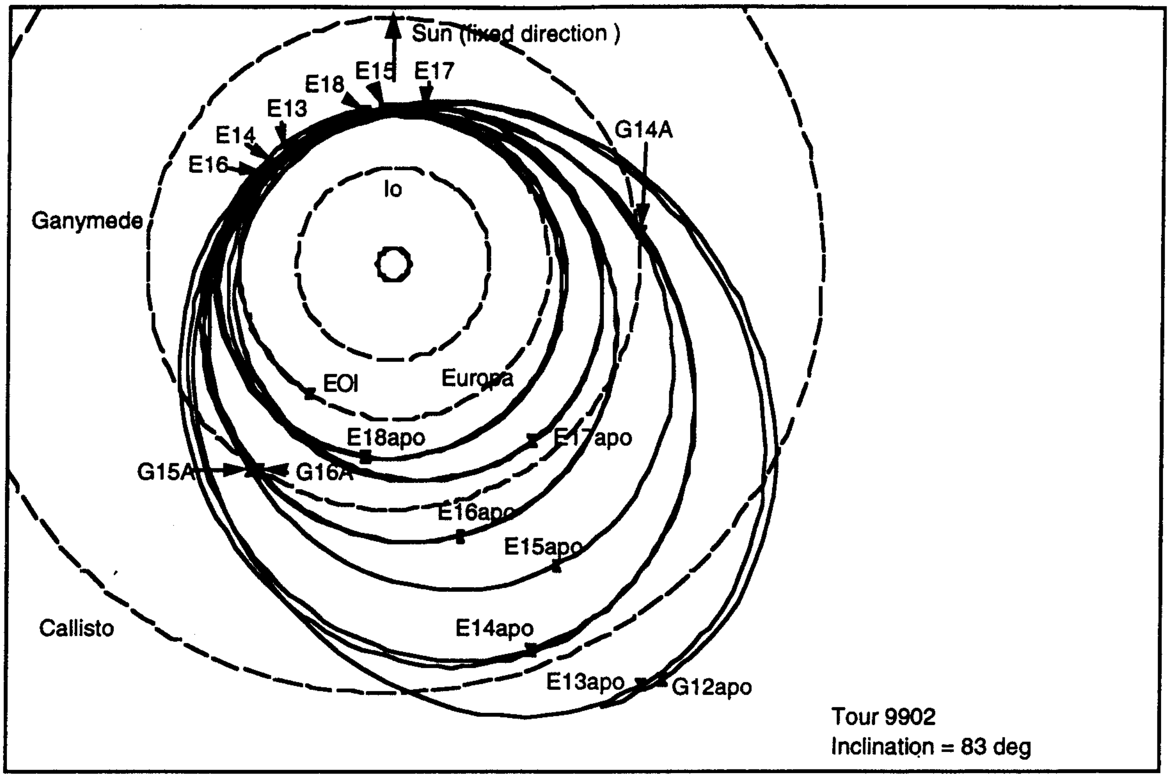


Figure 6 Tour with Traditional Endgame (Little Rotation of Line of Apsides)

Table 1
TYPICAL FLYBY CONDITIONS AND ΔV REQUIREMENTS FOR TRADITIONAL ENDGAME

Encounter	Resonance (E : S)	Date	Altitude (km/s)	V_∞ (km/s)	Period (days)	ΔV at Apojove After Flyby (m/s)
E13	3 : 1	12/28/07	11305	3.6	10.7	0.0
E14	5 : 2	1/8/08	200	3.7	8.7	0.0
G14A		1/15/08	20482	5.2	8.9	55.5
E15	2 : 1	1/25/08	200	3.1	7.3	0.0
G15A		1/27/08	94575	3.5	7.2	0.0
E16	5 : 3	2/2/08	167	3.1	5.7	0.0
G16A		2/3/08	15000	3.1	5.9	47.3
E17	4 : 3	2/19/08	209	2.3	4.7	150.9
E18	6 : 5	3/5/08	200	1.2	4.2	143.8
				Endgame Total:		397.5
EOI		3/27/08	200			521.2

Figure 7 shows a shortened endgame, which in this case (tour 9906), has only two Europa encounters before EOI because Ganymede gravity assist flybys can be used to drive the spacecraft period down farther until the apojove of the orbit is below Ganymede's orbit. It should be noted that both tours began with the same Jupiter arrival date and starting date for the satellite tour, but end with quite different endgames. Table 2 shows the details on the encounters and the ΔV which is representative of a shortened endgame.

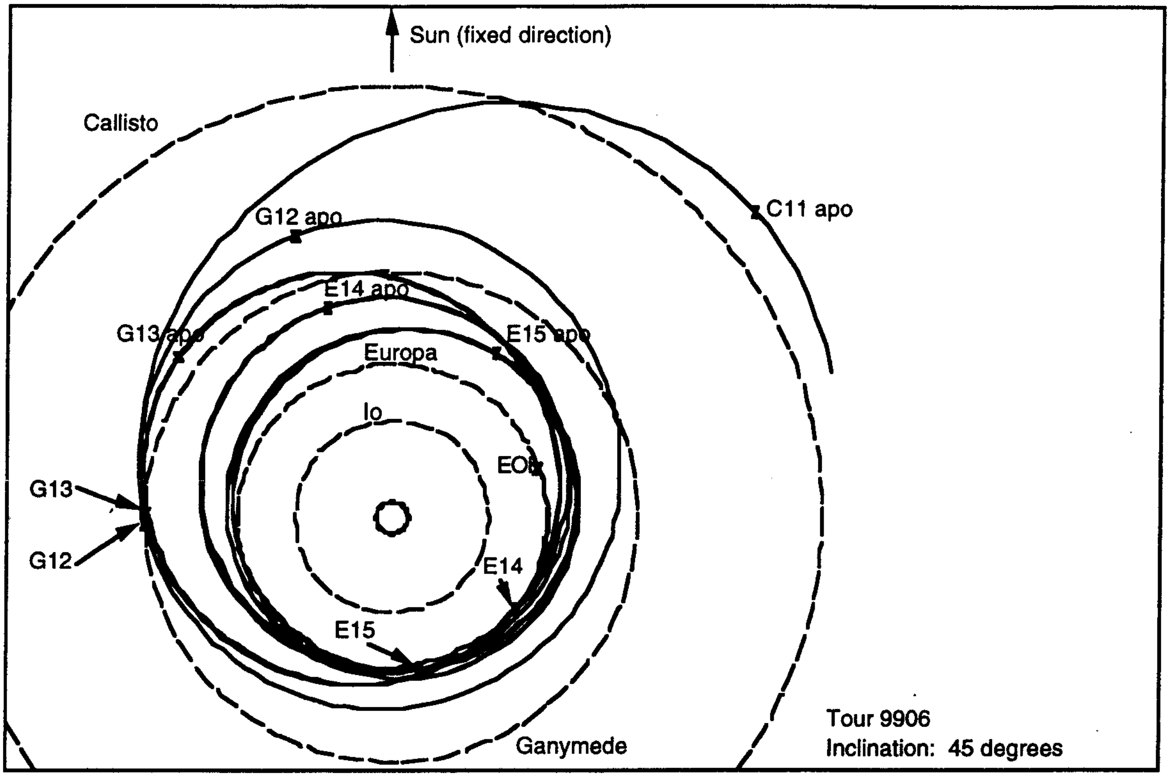


Figure 7 Tour with Shortened Endgame (Considerable Rotation of Line of Apsides)

Table 2
TYPICAL FLYBY CONDITIONS AND ΔV REQUIREMENTS FOR SHORTENED ENDGAME

Encounter	Resonance (E : S)	Date	Altitude (km/s)	V_∞ (km/s)	Period (days)	ΔV at Apojove After Flyby (m/s)
G12	2 : 1	3/23/08	410	2.4	7.2	0.0
G13	5 : 3	3/30/08	5135	2.5	5.7	0.0
E14	4 : 3	4/18/08	100	1.8	4.7	102.7
E15	6 : 5	5/2/08	575	1.2	4.2	173.3
				Endgame Total:		276.0
EOI	6 : 5	5/24/08	200			522.8

One striking difference between the two endgames is the difference in rotation of the line of apsides. The resulting shorter endgame has considerable rotation of the line of apsides, and EOI occurs in a noticeably different location as compared to the traditional endgame. The traditional endgame, on the other hand, has little rotation in the line of apsides. It may be possible to exploit these differences to obtain the desired node for the orbital phase at no additional ΔV cost. Issues such as telecom visibility may also limit acceptable endgame variations. The other important difference between the two types of endgames is that significant ΔV savings can be realized with the shortened endgame.

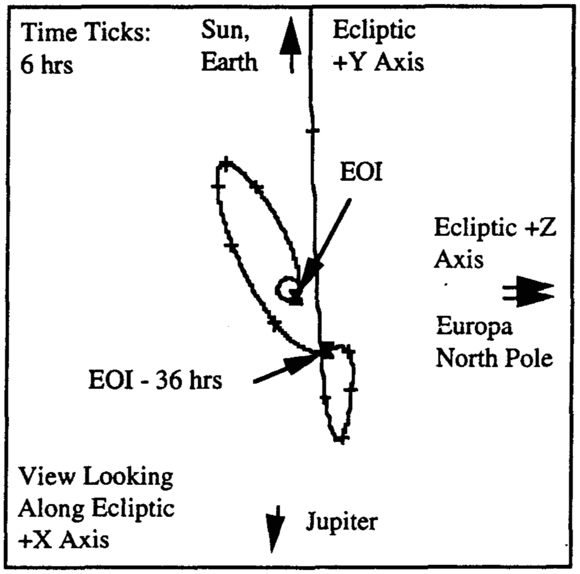
Navigation Complexities for Nontargeted Encounters

A nontargeted encounter is one whose flyby conditions cannot be precisely controlled. This is usually because another (lower altitude) encounter occurs on the same orbit. Tour designers attempt to avoid nontargeted encounters with altitudes less than 50,000 km (unless they are needed for science reasons, as in providing more global coverage in the Galileo mission) because their uncontrolled gravity-assist effect could cause large dispersions to the trajectory. In naming encounters, the letter "A" is usually appended to the encounter name to indicate a nontargeted encounter.

In the 9902 tour, the Ganymede encounters on orbits 14, 15, and 16 appeared when the "traditional" endgame was added to the tour. The G14A encounter at about 20,500 km altitude could be treated as a targeted encounter, since it is on a different spacecraft orbit than E14 or E15. The E15A encounter at 95,000 km altitude also presents no problems in precise navigation. The G16A encounter, on the other hand, occurs less than 32 hours after the E16 very low altitude flyby, and is at a lower limit of 15,000 km altitude. (The CATO optimization program would place this encounter at a lower altitude, if allowed to do so, to save deterministic ΔV.) A post-encounter maneuver, occurring one day after the E16 flyby, could not correct all of the trajectory dispersions from the E16 flyby. It is possible that Ganymede nontargeted encounters are a feature of the traditional endgame. Shortened endgames which begin at the 4:3 resonance are below Ganymede's orbit and will not have such nontargeted encounters.

Trajectory Approaching EOI

Figures 8a, 8b, 8c and 9 show the trajectory of the spacecraft during the final approach to Europa and EOI. This final phase looks the same whether the spacecraft has arrived via a "traditional" endgame or a shortened endgame. Figure 8b is a view from above the ecliptic plane with the trajectory drawn in an inertial coordinate system. Figures 8a and 8c are also inertial views and are the edge-on views of Figure 8b when looking toward the ecliptic +X axis or the ecliptic +Y axis, respectively.



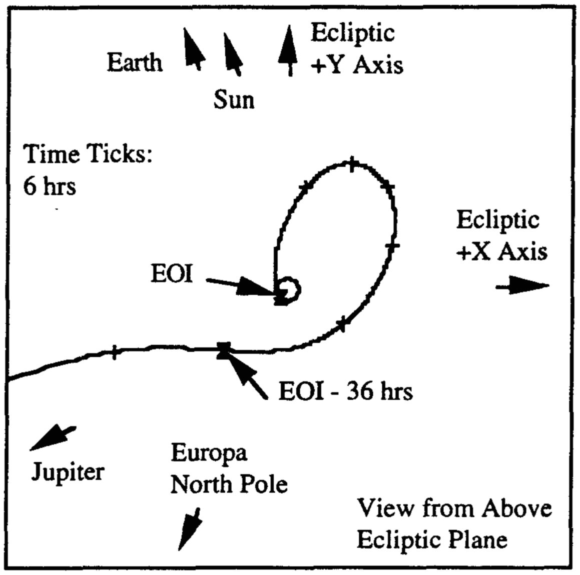


Figure 8a (Left) Inertial View of "Capture" Looking Along Ecliptic +X Axis
Figure 8b (Right) Inertial View of "Capture" Looking from Above Ecliptic Plane

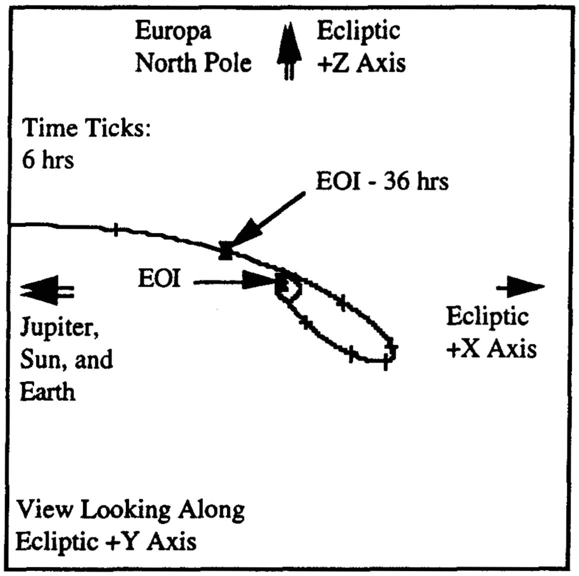


Figure 8c Inertial View of "Capture" Looking Along Ecliptic +Y Axis

Figure 9 is the comparable view to Figure 8b (from above the ecliptic plane) but in a rotating coordinate system, which has the direction to Jupiter fixed to be toward the top of the plot. This view is nearly the same as the view from Europa's North pole, since ecliptic north and Europa's north pole are only 2.2 degrees apart.

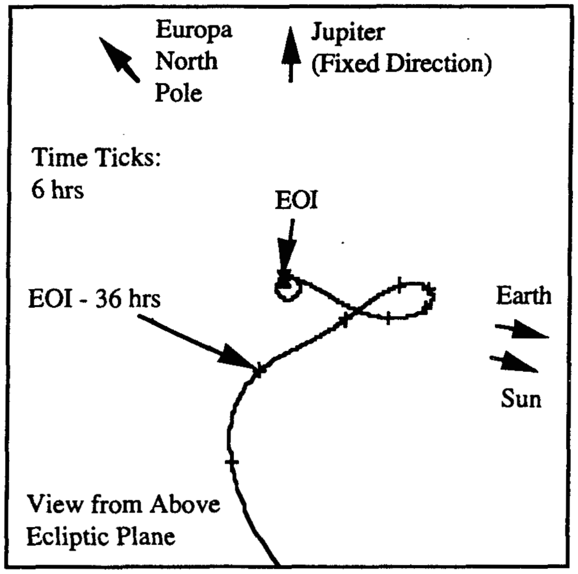


Figure 9 Jupiter-Fixed View of "Capture" from Above Ecliptic Plane

These figures clearly show the "capture" of the spacecraft by Europa. For the case illustrated, injection occurs over the northern hemisphere and the orbit about Europa has an inclination of 45 degrees. For other cases, the injection into an orbit about Europa sometimes occurs over the southern hemisphere.

Endgame and Orbit Insertion Complexities

The endgame phase (especially the elliptic approach and orbit insertion) is very challenging for the trajectory designers. The approach of constructing an endgame which followed the pattern of alternating inbound and outbound encounters and then trying to guess the orbit insertion time and geometry was tedious and largely unproductive. Convergence for a trajectory which utilizes Jupiter third-body effects is sensitive to the choice of EOI time. A new software tool was developed by Paul Finlayson at JPL to assist in the design of the endgame and geometry, and to provide better guesses for the EOI time and geometry prior to and just after orbit insertion into an inclined orbit about Europa. This tool mimics what was done previously when the trajectory demonstrating capture was shown to exist. This involves the forward integration of a trajectory with a sequence of Europa resonances ending at the apoapsis prior to EOI. Next a guess is made for the capture time and parameters for the orbit about Europa. That state is integrated backward with an EOI ΔV; adjustments are made to starting parameters and EOI ΔV to match up with the apoapsis.

ORBITAL PHASE

Orbit Altitude

The initial orbit about Europa after EOI is nearly circular. The current reference for this interim orbit has an altitude of 200 km at periapsis and 202 km at apoapsis. The final orbit is circular at 200 km altitude. The period of such an orbit is about 137 minutes and includes an eclipse and Earth occultation of the spacecraft by Europa ranging up to 50 minutes on each orbit. Every Eurosol (1 Eurosol = 1 Europan day = 3.55 Earth days) there is an eclipse and an Earth occultation by Jupiter lasting about 3.5 hours. Toward the end of the 30 day mission, the altitude may be lowered to 100 km.

Orbit Orientation

A highly inclined orbit is desirable in order to globally sample Europa (with 83 degrees being the reference value), but orbits with inclinations under 45 degrees have better long term stability[7,8]. There seems to be little ΔV cost associated with achieving any desired inclination for the orbit about Europa. The orbit orientation with respect to the sun and Earth are also important considerations. It is highly desirable to have the line of nodes between 20 and 50 degrees of the solar meridian in order to provide high quality imaging. The requirement that the Earth-Europa-node angle be between 10 and 80 degrees (in order to avoid tracking the spacecraft in orbits that are edge-on or face-on) is generally met if the requirement for orbit orientation with respect to the solar meridian is met.

Figure 10 shows an orbit about Europa with an inclination of 45 degrees. Note that the requirement that the line of nodes lie between 20 and 50 degrees of the solar meridian is not met for this case at EOI. However, for a 200 km altitude circular orbit at an inclination of 45 degrees, Europa J_2 perturbations will cause the node to regress (i.e., move clockwise as viewed from Europa's north pole) at a rate of about 3 degrees per day. At this nodal regression rate, the node will traverse 90 degrees during the 30-day orbital phase of the mission, so that the node will be within the 30-degree constraint region for about 10 days.

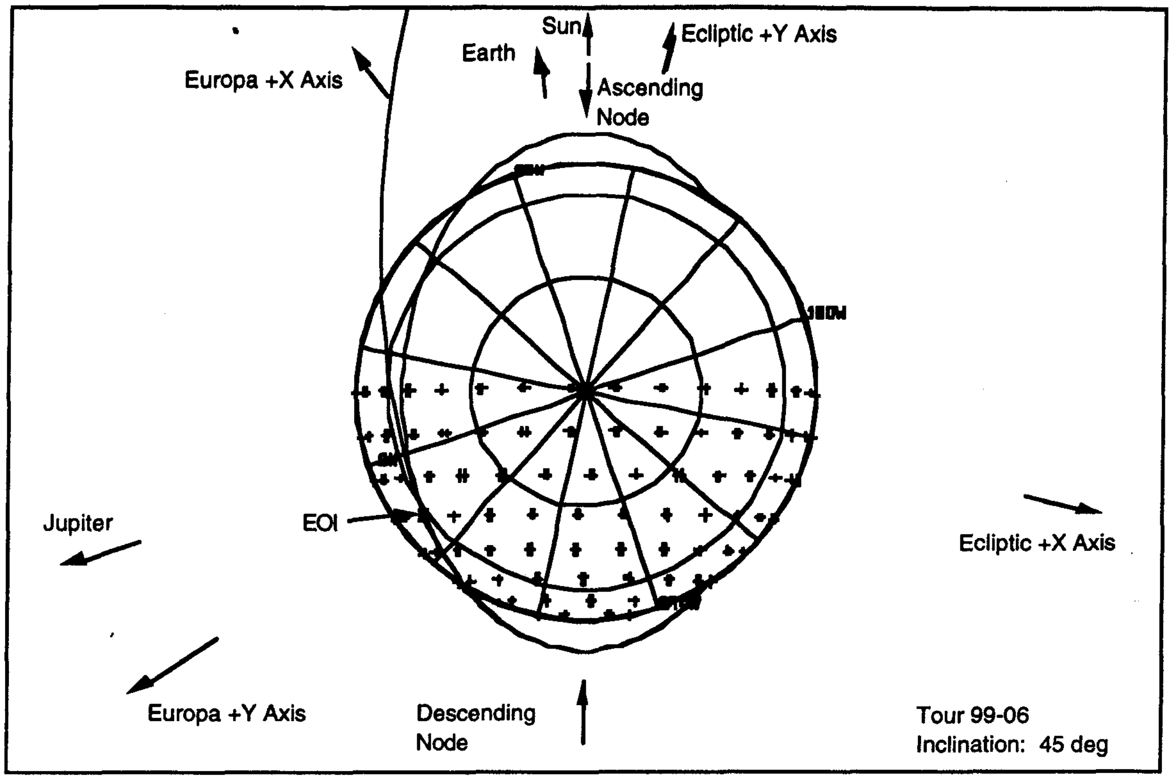


Figure 10 Europa North Pole View of Orbit About Europa (Inclination = 45 degrees)

Orbital Phase Duration

The orbital phase has a nominal duration of only 30 days. The radiation dosage during this phase alone is expected to be about 2 Mrad. An extended mission is possible; however, the intense radiation environment and the impending solar conjunction probably will not permit a very long extension.

FUTURE WORK

More detailed work remains to be done in the trajectory design area. Since the problem of designing endgames and orbit insertion appears to be solved, attention can be directed to various mission design trades. These include a lower C_3 requirement (which allows a higher injected mass at the cost of more interplanetary ΔV), the interplay of initial perijove range and initial orbit period on JOI and PJR ΔV, more serious consideration of a two satellite gravity assist, and limiting the number of arrival dates. The results of the assessment of radiation dosage for various tours, currently under evaluation, will need to be incorporated into satellite tour and endgame design. A better understanding is needed of the requirements for acceptable values for Europa orbit node and inclination, especially as they may pertain to telecom visibility at EOI.

CONCLUSIONS

Integrated trajectories have been designed go from launch to orbit about Europa. The Jupiter arrival and initial orbit phase features an inbound gravity assist flyby of Ganymede, Jupiter orbit insertion maneuver at 12.5 R_J, 200-day initial orbit, and small perijove raise maneuver. Each has a nearly ballistic satellite tour (from a two-body conic design by a Purdue University team) and an endgame with either (1) only one or two Europa encounters, or (2) with up to a half dozen Europa encounters. Third body perturbations from Jupiter permit the endgame phase to end with an elliptic approach (i.e., temporary "capture" by Europa) and reduce the ΔV cost of insertion about Europa. The deterministic ΔV cost from launch through Europa orbit insertion ranges from under 1.8 km/s for short endgames to about 2.0 km/s for endgames with six Europa encounters. An additional 0.3 km/s is allocated for correcting trajectory dispersions (statistical and navigation ΔV).

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